CONCRETE FORMWORK

FIELD OF THE INVENTION

This invention relates to stay-in-place formwork for creating vertical concrete structures.

BACKGROUND OF THE INVENTION

The use of stay-in-place modular formwork for creating vertical concrete structures such as walls is well known in the art. Canadian patents Nos. 2,215,939, 2,226,497, and 2,218,600 granted to Piccone provide suitable representative examples of prior-known modular formwork systems of the kind in which discrete inner and outer wall panels are assembled together (to create inner and outer formwork wall surfaces) by means of vertically-extending cross-panels or connector panels, sometimes referred to simply as "connectors", that span the inner and outer wall panels and connect them together, thereby creating a formwork assembly comprising a series of vertically extending cells into which concrete may be poured and left to harden. The connectors are typically formed with apertures permitting concrete to flow horizontally from one cell to another, permitting steel reinforcing bars (re-bars) to be placed horizontally to span a consecutive series of cells by running the re-bars through the apertures, and permitting concrete poured into a series of adjacent cells to form a continuous monolithic concrete structure.

Other cell-based modular formwork systems have also been previously described, but unlike the Piccone systems described in the Canadian patents noted above, are generally not sufficiently versatile to allow for the construction of concrete walls having dimensions that are outside a narrow range without sacrificing structural rigidity. By way of example, Nessa *et al.* in U.S. patent No. 5,216,863 disclose a system whereby a plurality of hollow vertical elements having (within a relatively narrow range of dimensions) a generally octagonal or circular cross-section are nested together to define a series of columns or channels into which concrete may be poured. In U.S. patent No. 5,491,947,

Kim describes a system wherein discrete inside and outside faceted wall panels are interconnected by a series of cross webs to similarly create a series of generally columnar formwork cells. For the construction of thicker walls, both Kim and Nessa *et al.* formwork systems contemplate the widening of the internal cross-panels without any corresponding expansion in the dimensions of the inside and outside panels (so as to avoid the waste of materials that would accompany the scale-up of octagonal cells) thereby to define a series of more-or-less rectangular channels that are supported only by cross-panels. This causes both the Kim and the Nessa *et al.* formwork systems to accordingly suffer from the deficiency noted above, and render them in particular poorly suited for the construction of concrete walls that are more than about 8 inches thick. The following discussion of the background of this invention will accordingly focus mainly on the modular formwork described in the above-noted Canadian patents granted to Piccone, which are considered to be more pertinent prior art.

As will be explained in greater detail below, the cellular configuration, which is common to all prior known modular stay-in-place formwork systems, including those described in the aforementioned Canadian Piccone patents, may complicate the assembly of the formwork, especially in situations where variations in the dimensions of the concrete structure are contemplated. The cellular configuration may also in some cases contribute to undesirable distortion of the resulting concrete structure.

Each cell of a prior-known modular formwork assembly of the sort described above is typically defined by two wall panels and two connectors. The connectors form the walls of the cell perpendicular to the panel walls, and the resulting cell typically has a generally rectangular cross-section. The complete formwork assembly may be constructed by propagating individual formwork cells one after another, each interior connector constituting a common wall of adjacent cells. It is, however, more common in practice to first assemble a series of alternating panels and connectors to create a comb-like inner or outer wall segment, and to subsequently close off the cells by adding on the opposite wall panels after conventional reinforcing steel rods have been placed inside the formwork assembly. Reinforcing rods are conventionally set within concrete structures for strengthening

purposes because concrete without reinforcement is not well suited to withstand tensile or shear forces. It is noted in this connection that the above-described octagonal formwork of Nessa *et al.* and the faceted formwork of Kim both limit the ability of a user to accommodate the placement of reinforcing rods in accordance with conventional building standards to suit various residential and commercial wall applications. For example, the preferred conventional placement of reinforcing rods in a basement wall that is set against backfill would be adjacent the inner wall surface - octagonal or faceted formwork renders such placement difficult or impossible.

Stay-in-place formwork is preferably manufactured from lightweight materials such as PVC plastic, and is generally thin relative to the thickness of the concrete structure or wall. As a result, the wall panels of stay-in-place formwork assemblies tend to distend or bow outwardly under the weight of the concrete that is poured into any given cell of the formwork assembly. This bowing effect is commonly referred-to in the art as "pillowing". As mentioned above, the connectors of known modular formwork systems are typically perforated to allow concrete that is poured into one cell to cross over into an adjacent cell; this facilitates the pouring of the concrete as it is not necessary to separately pour concrete into each individual cell. If the perforations are of adequate size, the cross-flow of poured concrete into adjacent cells usually prevents a similar bowing of the connectors under the weight of the poured concrete. The cross-flow of concrete and cross-placement of reinforcing rods between individual cells (through the perforations) also increases the overall strength and rigidity of the resulting concrete structure.

Pillowing of a formwork assembly may result not only in the unsightly appearance of the outer surface of the resulting concrete structure, but may also lead to undesirable distortion of the resulting concrete structure, especially in cases where the pillowing is uneven as between cells or within a given cell. To completely eliminate pillowing in a stay-in-place formwork assembly, it would generally be necessary to either fabricate the wall panels from unacceptably thick and heavy materials, or to externally brace the wall panels while the poured concrete hardens. Pillowing is accordingly sought to be limited (although it is normally not entirely avoided) in known stay-in-place formwork assemblies through the

use of internal auxiliary tensioning panels (frequently referred to in the industry as "braces") that, like the wall panels and connectors, typically extend along substantially the entire vertical extension of the formwork. Braces may be associated with connectors, in which case they usually depend at a comparatively shallow angle from a point of connection on the central portion of the connector (so as to limit bending of the braces when concrete is poured into the assembly) and interconnect with supplementary connection or interconnection means provided on the inside surface of the wall panels, or they may be independent of connectors, in which case they extend generally perpendicularly between and communicate with the supplementary connection means on the inside surfaces of the inner and outer wall panels in a given cell. It will be understood, of course, that the connectors themselves also function to limit the pillowing of the wall panels along their edges when the concrete is poured; in this sense, the connectors of known formwork assemblies also act as tensioning elements or panels placed under tension by the weight of concrete in the formwork.

Since the wall panels of known formwork assemblies are joined together by means of connectors that interconnect with the wall panels along their edges, the horizontal width of each cell is thus defined mainly by the width of the inner and outer wall panels, but also by at least a portion of the thickness of the corresponding connectors at either end. Any two adjoining cells of known formwork assemblies will accordingly have a total horizontal width being the sum of (a) the width of two adjacent wall panels, plus (b) the thickness of the connector between the cells, plus (c) at least a portion of the thickness of the connectors at either end of the two-cell structure. In other words, assuming wall panels of uniform dimensions and connectors of uniform thickness, the total length of a formwork wall divided by the number of cells in that wall gives a resultant cell width that exceeds the width of a wall panel by something in excess of the thickness of a connector, the "something in excess" varying depending upon the number of cells. Since the horizontal extension of each given cell of a prior known cellular formwork assembly is defined not only by the width of the corresponding inner and outer wall panels of that cell but also by at least a portion of the thickness of the associated connectors at either end, and since the connectors also act as tensioning panels, it may be difficult to locate the internal auxiliary

tensioning panels (braces) at precisely even distances from the connectors at either end and from one another along the width of a cell; (*i.e.* it may be difficult to maintain an even spacing between the connectors and the tensioning panels within a given cell of known modular formwork, especially if both tensioning panels that are associated with connectors and independent tensioning panels are present in a given cell). This may cause uneven pillowing, which in turn could lead to the undesirable distortion of the resulting concrete wall or structure.

It is contemplated in known formwork systems to provide connectors in different widths in order to allow for the construction of walls (or other structures) of different thicknesses, but complications may also arise in the use of known formwork assemblies when one desires to construct a wall or structure that has more than a single uniform thickness. In particular, since each given wall panel of a known modular formwork assembly relies on associated connectors for its interconnection with adjacent wall panels, variations in thickness of the concrete structure cannot be readily accommodated without requiring the production and use of a multitude of unique special-purpose formwork panels, connectors, or other associated components that allow one to maintain a desired relatively consistent spacing of tensioning panels within the assembly. Of course, the production of these special-purpose formwork panels, connectors, and components increases the cost of construction, and the requirement for their use complicates the assembly of the formwork structure.

SUMMARY OF THE INVENTION

As discussed above, undesirable uneven pillowing may arise in a formwork assembly unless the assembly is relatively consistently internally supported by connectors and/or tensioning panels. It is therefore an object of one aspect of the present invention to provide a concrete formwork system (and individual components thereof) that enables the construction of a formwork assembly in which a desired regular spacing of internal supporting members is readily maintained (thereby promoting uniformity in pillowing). It

is also an object of the present invention to provide a formwork system (and individual components thereof) that enables the construction of a formwork assembly that is readily scalable, such that desired variations in the thickness or other dimensions of the concrete structure can be accommodated without requiring the production and use of a multiplicity of unique individual components.

In accordance with one aspect of the present invention, there is provided a stay-in-place formwork assembly in which the wall panels are suitably configured to be joined to one another (directly or *via* clips) and held in spaced-apart relationship by perforated support panels attached by suitable interconnection or fastening means to the interior wall surfaces of the wall panels. The support panels perform the wall-tensioning functions of the connector panels of the prior art described above, but do not also function to join adjacent inner or adjacent outer wall panels to one another, and may accordingly be located at any desired position within the interior of the formwork assembly. The support panels are normally spaced at regular intervals within a formwork assembly in accordance with preferred embodiments of the invention (that are manufactured of PVC plastic material) in order to encourage the even pillowing of the assembly when concrete is poured into it, but may of course also be located at irregular intervals if it is desired to achieve a particular distorted effect. Both the wall panels and the support panels in preferred embodiments are elongate and vertically-extending, much like the wall panels and connectors of the prior-known cellular formwork discussed above. (In this specification, although reference is made to "vertical" and "horizontal" extensions of elements or assemblies, it is to be understood that, depending upon the situation, these terms must be understood to be relative terms and not absolute terms. For example, for aesthetic reasons, it may be desired to form concrete so that the generally vertical boundary walls of the finished structure are at an angle to the vertical instead of absolutely vertical. Or for some culvert or tunnel work, forms disposed at a nearly horizontal orientation may be required. However, the typical application of the invention is for construction of formwork intended for the formation of generally vertically disposed concrete walls.)

Also contemplated within the scope of the invention are the individual elements

(components) of the novel formwork assembly disclosed herein, kits comprising such components, concrete structures made with and incorporating such components, and a system of stay-in-place formwork wherein the various components and combinations of components of the formwork assembly are deployed. A further aspect of the invention is the provision of a system of stay-in-place formwork that can accommodate desired variations in the thickness or other dimensions of the concrete structure to be cast without requiring the production and use of a multitude of unique individual formwork components. In one preferred embodiment, a system of stay-in-place formwork for the construction of typical 4 to 36 inch wide commercial and residential concrete walls that accommodates frequently desired variations in the thickness or other dimensions of such walls, and that comprises only seven distinct essential formwork components, is provided.

As set out in greater detail below, since the support panels (unlike the connectors of prior known formwork assemblies) do not function to join adjacent inner and adjacent outer wall panels together in a cellular arrangement, the construction of an assembly of the present formwork may be considerably simplified while still maintaining a desired regular interval between internal support for the wall panels. By way of example, it is possible to construct an assembly of the inventive formwork in which the wall panels that make up the inner and outer wall surfaces of the assembly (and, of course, also of the resulting concrete wall once the concrete is cast) are of different widths; (*e.g.* it is possible to construct a partial formwork assembly in which three four inch wide wall panels are used to make up an inner wall section, and two, four, and six inch wide panels are used to make up the corresponding outer wall section). Similarly, whether or not all of the wall panels used in a given construct are of the same width, the elimination of reliance upon a cellular arrangement within the formwork allows for the construction of an assembly in which the joints between the wall panels that make up the inner wall surface of the assembly are not aligned with the corresponding joints between the wall panels of the other wall surface.

As will be appreciated from the description below, a further result of the elimination of reliance upon a cellular arrangement within the formwork assembly is the ready scalability of the assembly to accommodate desired variations in the thickness of a wall or

structure, and the reduction in the number of individual formwork elements that are required to be produced and utilized in the construction of a given wall or structure. This, of course, leads to reductions in both manufacturing and labour costs, as well as increased efficiency in the construction of a wall or structure.

As with prior known stay-in-place formwork assemblies, the formwork of the present invention is preferably manufactured from lightweight plastic (such as PVC) or other lightweight materials in order to minimize transportation costs and to facilitate the assembly and handling of a relatively large section of assembled formwork prior to the pouring of concrete into it. The interconnections between components of the formwork assembly (including those between adjacent wall panels and between wall panels and support panels) are preferably releasable interconnections of the sort that may be achieved by means of the slidable engagement of co-operating T-fasteners with the mating female receptacles (or by means of other suitable fastening means known to those of skill in the art). This permits a worker to dis-assemble and re-configure a section of formwork assembly if modifications are desired to be made before the concrete is poured; of course, once concrete is cast within the formwork assembly, the panels and members (and any other included components) of the stay-in-place assembly are also set in place. Although some seepage may be tolerated, the engagement between the external wall panels and elements of the formwork assembly must be sufficiently tight as to prevent the poured concrete from leaking out of the formwork assembly before it hardens, and must extend essentially along the entire vertical extension of the formwork (or at least as high as the concrete is intended to be poured). A greater degree of seepage may be tolerated between the inner connections of the assembly, but of course these must also be sufficiently sturdy to avoid breaking or disengaging under the weight of poured concrete.

Various kinds of conventional interconnection means that satisfy the above criteria may be employed, and in preferred embodiments the wall panels have interconnection means for engaging adjacent panels (along their longitudinal edges) that are complementary in the sense that the interconnection means on the first edge of one panel will cooperate with the interconnection means on the opposite or second edge of an

adjacent panel, but the first edges of two wall panels will not cooperate. For example, if cooperating conventional T-fasteners are utilized, then each panel will include a male T-fastener formed along one longitudinal edge and a corresponding generally C- or channel-shaped female fastener along the other edge. The resulting "directionality" of the wall panels reduces the number of differently configured wall panels and components that need to be used in the construction of a given formwork assembly. As discussed further below, if the selected interconnection means between the wall panels are complementary in the sense described above, then directionality reversing wall panels (that may have, for example, male T-fasteners at both ends or channel-shaped female fasteners at both ends) may also be included within the formwork system of the invention in order to facilitate the construction of a formwork assembly that includes corners or other dimensional variations.

As an alternative, adjacent wall panels may be interconnected *via* discrete clips that, unlike the connectors of known modular formwork systems, do not span between inner and outer wall panel segments so as to create a cellular internal structure within the formwork. As a further alternative, universal interconnection means (of the sort that do not rely on differently configured complementary male and female portions, and that would permit the joining of the wall panels together in any orientation) may be utilized. The use of universal interconnection means between the wall panels (and between the wall panels and other components of the formwork system) would further simplify the propagation of the formwork assembly during construction of a wall section, and would also, of course, obviate the need for the directionality reversing wall panels discussed above (since the wall panels would not be directional in the first place). However, currently available universal interconnection means that satisfy the criteria set out above are relatively expensive to manufacture, and may undesirably increase the cost of manufacture of a formwork assembly in accordance with the invention.

The wall panels also include suitable support interconnection means (such as conventional T-fasteners) distributed along their inner surface at selected suitable intervals across the width of the panels in order to provide anchoring points for the support panels.

In preferred embodiments, the distribution of support interconnection means begins substantially at the edge of the wall panels, such that the joint between any two adjacent wall panels is supported internally by a support panel. However, it is also within the scope of the invention to provide wall panels in which the distribution of support interconnection means begins at a position that is offset from the longitudinal edges of the wall panels. The support panels (discussed in further detail below) will, of course, have cooperating interconnection means along their longitudinal edges to engage the inwardly disposed interconnection means of the wall panels. As noted above, the interval between these inward-facing support interconnection means of the wall panels may be irregular if desired, but in preferred embodiments the interval is regular in order to allow for the maintenance of a regular spacing of support, and thus minimize uneven pillowing of the formwork assembly under the weight of poured concrete. In one preferred embodiment of formwork intended for the construction of the walls of residential or commercial buildings, the interval between neighboring inward-facing support interconnection means on the wall panels is 2 inches; in a similar (metric) embodiment, the interval is 5 centimeters.

The selected regular interval between support interconnection means on the wall panels is preferably conserved as a unit measure of width (after suitable allowances have been made for the space taken up by the interconnection means present along the edges of the wall panels and between the wall panels and support panels) relative to all wall panels and support panels of a given formwork assembly in accordance with the invention. For example, an assembly in which the interval between neighboring inward-facing support interconnection means on the wall panels is 2 inches will be dimensioned such that all wall panels and support panels have overall effective widths (after taking into account the allowances mentioned above) that are multiples of 2 inches. The resulting proportionality of the formwork assembly not only enhances its structural rigidity (thereby further promoting consistency of pillowing), but also facilitates the scalability of the assembly such that desired variations in dimension of the wall or structure to be cast are readily accommodated without corrupting the regularity of support, and without requiring special-purpose panels and members to be manufactured and used. If relatively fine variations in the dimensions of a concrete structure are contemplated, then formwork having a

relatively narrow (small) unit measure of width may be selected; if only gross variations (or no variations) in the dimensions of the structure are contemplated, then formwork having a relatively wide (large) unit measure of width may be preferred. As noted above, a 2 inch unit measure of width (or a 5 centimeter unit measure of width for buildings intended to be constructed in metric measurements) has been found to be suitable for most commercial and residential concrete wall building applications.

As with the connectors of the prior known formwork assemblies discussed above, the support panels of the present invention are preferably elongate in the vertical orientation and include suitably dimensioned perforations (the basics relating to the selection of the preferred size and dimensions of which would be within the ordinary skill of a person skilled in the art - further improvements relating to the preferred size and dimensioning of the perforations are disclosed in the applicant's Canadian patent application no. 2,352,819) to permit the cross-flow of concrete and the cross-placement of reinforcing steel rods between sections of assembled formwork. Just as the inadequacy of the cross-flow of concrete between cells of a prior known formwork assembly may lead to the bulging of one cell relative to another, (which may in turn lead to undesirable distortion of the concrete structure), inadequacy in the cross-flow of concrete between sections of formwork assembly in accordance with the invention may result in the bulging of one section relative to another. It will be understood, of course, that multiple short support panels may be used in place of any given preferred elongate support panel provided that suitably dimensioned perforations are maintained (such as might be achieved, for example, with the use of intervening open spacers), but that the construction of an assembly using multiple short support panels in place of fewer elongate support panels would increase the amount of labour required to complete a section of formwork assembly (and thus increase labour costs relative to the construction of a concrete wall utilizing the formwork of the invention).

In order primarily to save formwork material (and hence reduce manufacturing costs), the support panels of the present invention may include one or more associated auxiliary tensioning panels or "braces". Such auxiliary tensioning panels take the place of

separate support panels that would otherwise need to be included in a formwork assembly in order to prevent undesirable pillowing, and (as will be seen in greater detail below), may also simplify the maintenance of a regular interval of support of the formwork assembly around corners, or where various alterations to the dimension of the formwork structure are contemplated. Similar to the way that auxiliary tensioning panels may be associated with the connectors of the prior known formwork assemblies discussed above, the auxiliary tensioning panels of the invention depend at a relatively shallow angle from a support panel to mate with an adjacent inward-facing support interconnection means of a wall panel. The connection between the support panel and the auxiliary tensioning panel may be permanent (such that the auxiliary tensioning panel at the zone of connection is integral with the support panel) or releasable (employing known types of complementary interconnection means such as sliding T-fasteners) depending, in part, upon the physical characteristics of the material from which the support panel is constructed. In alternate preferred embodiments described herein that are manufactured of PVC plastic material, the connection may be either permanent or releasable, and is in either case offset far enough away from the nearest edge of the support panel to permit the auxiliary tensioning panel to depend at a comparatively shallow angle (preferably no more than about 45°) from the support panel so as to limit flexing of the auxiliary tensioning panel under the weight of concrete poured into the formwork assembly. The offset of the zone of connection from the nearest edge of the support panel in preferred embodiments (in which a unit measure of width is conserved relative to all wall panels and support panels) is thus one unit measure of width, or a whole number multiple thereof if longer tensioning panels are desired to be used. Since the support interconnection means of the wall panels are similarly spaced apart across the width of the wall panels in unit measures of width, a 45° angle of dependency will be maintained if the offset of the zone of connection is similarly spaced at whole number multiples of unit measures of width from the nearest edge of the support panels.

Although not preferred, at least in cases where the wall panels are made of extruded PVC plastic or similar one-piece material, wall panels that include permanently associated tensioning panels could also be utilized in a formwork assembly in accordance with the

invention. Since the external surface of a wall or structure made using the inventive formwork (unless it is overlaid) will be defined by the wall panels of the formwork, the wall panels are typically manufactured from material that has an aesthetic surface appearance. The inner components of the assembly (including support panels, tensioning panels, and other internal components discussed below) may be made of less costly materials that retain the requisite physical characteristics of the formwork, but do not match the selected aesthetic quality of the external surface of the wall panels.

To further enhance the scalability of the formwork, internal connecting elements configured to engage two or more support panels in end-to-end relationship may also be provided. (It will be noted that the interconnection means provided on such connecting elements will thus preferably correspond to those that are selected for the inward facing support interconnection means of the wall panels discussed above). The ability to connect two or more support panels in end-to-end relationship within a formwork assembly extends the reach of the support panels in expanded sections of formwork without requiring the manufacture of support panels in expanded widths. For example, a 36-inch thick wall section may be supported using sets of three 12-inch wide support panels (or sets of six 6-inch wide support panels, *etc.*) connected together within the formwork assembly, thereby eliminating the need to manufacture and use 36-inch wide support panels. Although linear connecting elements (that could be used to link two support panels together in end-to-end relationship as explained above) may be provided, it is also desirable in some instances to enhance the structural rigidity of the formwork assembly by permitting internal perpendicular cross bracing. Accordingly, generally box-shaped or cross-shaped four-way connecting elements may be preferred. Given that one objective of the inventive system of stay-in-place formwork is to enable the construction of a concrete wall or structure of variable thickness or dimension without requiring the production and use of numerous discrete formwork components, it will be understood that four-way connecting elements may generally be used in place of linear connecting elements, and that linear connecting elements need not be included among the elements that make up a complete stay-in-place formwork system that satisfies the scalability objectives of the invention.

As noted previously, the external surface of a concrete wall or structure that has been constructed using stay-in-place formwork is defined along its sides by the wall panels (unless the wall panels are subsequently overlaid with another surface material such as stucco). For straight wall sections that have been constructed using the inventive formwork, the two wall ends may similarly be defined by the terminal support panel at each end of the wall (provided that non-perforated terminal support panels are used), and any overreaching bits of formwork may be trimmed off if desired in order to improve the aesthetic quality of the wall end (especially if it is not to be overlaid). However, in many building construction applications, it is also desired to construct continuous concrete walls that include corners. For this purpose, outer corner panels that are suitably dimensioned and configured along their longitudinal edges to engage the outer terminal wall panels of two generally perpendicular wall sections, and inner corner elements that are configured to similarly engage the corresponding inner terminal wall panels of the two wall sections may be provided within the system of formwork of this invention. Of course, outer corner panels and inner corner elements that join together two wall sections that approach one another at other than a perpendicular angle may also be provided. In preferred embodiments, the outer corner panels extend one unit measure of width in both directions from the outer point of the corner, and the inner corner elements also include two perpendicularly arranged internal support interconnection means to facilitate alternative possible interconnection of the wall panels and support panels about the inner point of the corner.

Other forms and aspects of the invention will be appreciated by those skilled in the art having reference to the foregoing discussion, the following detailed description of preferred embodiments, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

In drawings that illustrate embodiments of the invention, Figures 2 and 18 to 22 illustrate partial formwork assemblies, all in plan view, and Figures 3 to 17 illustrate, again in plan view, formwork components suitable for constructing such formwork assemblies

and others. Figures 23 to 29 illustrate another embodiment of the invention in which adjacent wall panels are interconnected by clips.

Figure 1 is a schematic plan view of a partial assembly of cellular stay-in-place formwork in accordance with the prior art;

Figure 2 is a schematic plan view of a partial assembly of stay-in-place formwork in accordance with an embodiment of the invention illustrating one possible inter-relationship of wall panels, support panels, and tensioning panels suitable for making a concrete wall having two flat parallel sides;

Figure 3 is a plan view of a single-unit-width wall panel in accordance with an embodiment of the invention;

Figure 4 is a plan view of a four-unit-width wall panel in accordance with an embodiment of the invention;

Figure 5 is a plan view of a single-unit-width support panel in accordance with an embodiment of the invention;

Figure 6 is a plan view of a two-unit-width support panel in accordance with an embodiment of the invention;

Figure 7 is a plan view of a three-unit-width support panel in accordance with an embodiment of the invention that includes inset paired spaced female receptacles for receiving the terminal male fasteners of tensioning panels, the female receptacles each being inset by one unit of width from the nearest vertical edge of the support panel, one receptacle of each pair lying on either side of the support panel;

Figure 8 is a plan view of a five-unit-width support panel in accordance with an embodiment of the invention that includes inset paired spaced female receptacles for

receiving the terminal male fasteners of tensioning panels, the female receptacles each being inset by one unit of width from the nearest vertical edge of the support panel, one receptacle of each pair lying on either side of the support panel;

Figure 9 is a plan view of a single-unit-width direction-reversing wall panel in accordance with an embodiment of the invention;

Figure 10 is a plan view of a tensioning panel in accordance with an embodiment of the invention;

Figure 11 is a plan view of an inner corner element in accordance with an embodiment of the invention;

Figure 12 is a plan view of a four-way female receptacle element in accordance with an embodiment of the invention;

Figure 13 is a plan view of an outer corner dual wall panel in accordance with an embodiment of the invention;

Figure 14 is a plan view of an ornamental four-unit-width wall panel in accordance with an embodiment of the invention;

Figure 15 is a plan view of an ornamental three-unit-width wall panel in accordance with an embodiment of the invention;

Figure 16 is a plan view of another ornamental three-unit-width wall panel in accordance with an embodiment of the invention;

Figure 17 is a plan view of another ornamental three-unit-width wall panel in accordance with an embodiment of the invention;

Figure 18 is a schematic plan view of a partial assembly of stay-in-place formwork illustrating one possible inter-relationship of wall panels, ornamental wall panels, support panels, outer corner panels, inner corner elements, and tensioning panels in accordance with embodiments of the invention suitable for forming a concrete wall corner having outer flat surfaces and ornamentally configured inner surfaces;

Figure 19 is a schematic plan view of a partial assembly of stay-in-place formwork illustrating one possible inter-relationship of wall panels, support panels, tensioning panels, outer corner panels, and inner corner elements in accordance with embodiments of the invention suitable for forming a concrete wall corner having flat surfaces;

Figure 20 is a schematic plan view of an alternative partial assembly of stay-in-place formwork illustrating one possible inter-relationship of wall panels, support panels, tensioning panels, outer corner panels, inner corner elements, and four-way connecting elements in accordance with embodiments of the invention suitable for forming a concrete wall corner having flat surfaces;

Figure 21 is a schematic plan view of an alternative partial assembly of stay-in-place formwork illustrating another possible inter-relationship of wall panels, support panels, tensioning panels, outer corner panels, inner corner elements, and four-way connecting elements in accordance with embodiments of the invention suitable for forming a concrete wall corner having flat surfaces; and

Figure 22 is schematic plan view of a partial assembly of stay-in-place formwork illustrating one possible inter-relationship of wall panels, support panels, tensioning panels, outer corner panels, inner corner elements, and four-way connecting elements in accordance with embodiments of the invention suitable for forming a concrete wall having different thicknesses over its horizontal extension.

Figure 23 is a is schematic plan view of a partial assembly of stay-in-place formwork in accordance with a further embodiment of the invention in which adjacent wall panels are

connected *via* clips;

Figure 24 is a plan view of a four-unit-width wall panel in accordance with the embodiment of Figure 23.

Figure 25 is a plan view of a one-unit-width wall panel in accordance with the embodiment of Figure 23.

Figure 26 is a plan view of a wall panel clip in accordance with the embodiment of Figure 23.

Figure 27 is a plan view of a tensioning panel in accordance with the embodiment of Figure 23.

Figure 28 is a plan view of an inner corner element in accordance with the embodiment of Figure 23.

Figure 29 is a plan view of an outer corner dual wall panel in accordance with the embodiment of Figure 23.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The accompanying drawings illustrate formwork components and partial assemblies of such components in plan view. Each of the formwork components shown in the drawings are elongate into the plane of the drawings.

Referring to Figure 1, there is illustrated one completed cell 11 (and two adjoining partially completed cells 13) of a typical prior art formwork assembly 10. The assembly 10 includes discrete wall panels 12 that are placed in edge-to-edge relationship to define inner and outer wall segments after being interconnected and held in spaced-apart relationship

by means of perforated connector panels 14 *via* elongate terminal female receptacles 16 and mating male fasteners 18. The female receptacles 16 extend along the longitudinal edges of the wall panels 12 while terminal male fasteners 18 extend substantially along the longitudinal edges of the connector panels 14. (These elements are referred to as "terminal" because they are located at the ends, in plan view, of the wall panels 12 and connector panels 14, respectively. Note also that which element of a pair is male and which is female is arbitrary.) In the embodiment illustrated, female receptacles 16 are fixed to or integral with the side edges of the wall panels 12, while double male fasteners 18 slid within adjacent mating female receptacle receptacles 16 serve to interconnect adjacent wall panels 12 with an intervening connector panel 14, thereby fixing the adjacent wall panels 12 to one another *via* the intervening connector panel 14. Note also that both the connector panels 14 and wall panels 12 are provided with male fasteners inset from their side edges, those of the wall panels 12 being designated by reference numeral 26 and those of the connector panels 14 being designated by reference numeral 24. The purpose of these inset male fasteners 24, 26 will be explained below.

As discussed above, the overall width of each completed cell 11 of the prior known formwork assembly 10 is defined by the width of wall panel 12 forming that cell 11 and some portion of the thickness of each connector panel 14 at either end of that cell 11.

Auxiliary tensioning panels (braces) 20 that are associated both with the connector panels 14 and the wall panels 12 are also shown in Fig. 1. The braces 20 are interconnected between the connectors 14 and wall panels 12 *via* terminal female receptacles 22 along the longitudinal edges of the tensioning panels 20 and mating inset male fasteners 24 and 26 respectively of the connector panels 14 and wall panels 12. For uniformity, all female receptacles 16, 22 are identically configured and dimensioned, as are all male fasteners 18, 24 and 26. As explained above, the tensioning panels 20 contribute to the rigidity of the formwork 10 and limit the outward bulging or distension of the wall panels 12 under the weight of concrete that is poured into the cells 11.

Turning to Figure 2 and following figures, the components illustrated are preferably

constructed of relatively thin, suitably strong PVC plastic or similar material. Figures 3, 5, 9, 10, 11, 12, and 13 illustrate preferred embodiments of seven different formwork components that are sufficient for the construction of typical four-inch to 36-inch thick commercial or residential concrete walls that include typically desired (or required) variations in thickness and other dimensions. Figures 2 and 18 through 22 illustrate partial assemblies of formwork that demonstrate various possible inter-relationships of the formwork components to create walls or structures of various dimensions. Figures 4, 6 to 8, and 14 to 17 illustrate further components that are useful for building more elaborate formwork, or that facilitate the assembly of formwork of certain configurations. The remaining drawings (Figures 23 to 29) illustrate an alternative embodiment of the invention in which adjacent wall panels are connected *via* clips.

Referring to Figure 2, there is illustrated a partial assembly 28 of formwork in accordance with a preferred embodiment of the invention. By way of general overview, elongate and substantially flat wall panels 30 (each having an inward-facing surface 31A and an outward-facing surface 31B) have a terminal male panel fastener 34 at one vertical side edge and a terminal female panel receptacle 32 at the opposite vertical side edge. As will be discussed further below, a female support panel connector 38 is associated in back-to-back relationship with each terminal panel receptacle 32 of the illustrated embodiment for mating connection to a mating terminal male fastener of either a tension panel 40 or a support panel 36. Additional panel connectors 38 that depend from the inward-facing surfaces 31A of the wall panels 30, but that are not associated with a terminal panel receptacle 32 are also contemplated.

A series of such wall panels 30 are releasably interconnected directly to one another in edge-to-edge relationship to create wall segments *via* wall panel interconnection means comprising, for each pair of adjacent wall panels 30, a proximal female panel receptacle 32 and a mating male panel fastener 34. Two substantially parallel facing wall segments (each normally comprising a plurality of wall panels 30) generally indicated as 27, 29 are releasably interconnected in spaced-apart relationship at selected intervals along their width by plural generally perpendicularly-oriented support panels 36 that are

configured to communicate with support panel connectors 38 on the opposing inward-facing surfaces 31A of the wall panels 30. The width of the wall panels 30 and the width of the support panels 36 is preferably proportionate, such that the overall effective width of either one of the wall panels 30 and support panels 36 (after necessary allowances have been made for any space taken up by the interconnection means between them) will be a whole number multiple of the effective width of the other in order to facilitate the scalability and maintenance of structural rigidity of the resulting assembly. Tensioning panels 40 that span between wall panels 30 and support panels 36 may be included in place of some support panels 36 if it is desired to lower material costs (relative to the use of only support panels 36). Further details regarding the inter-relationship between the components of the formwork, and of the preferred methods of assembling a formwork structure in accordance with the invention, are set out below.

It will be recalled from the more detailed discussion in the summary provided above that a unit measure of width is defined in preferred embodiments of the invention by the selected regular interval or distance between consecutive support panel connectors 38 that are present across the width of the inward-facing surfaces 31A of the wall panels 30. Maintenance of a regular interval of support for the wall panels 30 promotes even pillowing, thereby increasing the aesthetic quality of the resulting concrete structure, as well as lowering the likelihood of unwanted distortion in the resulting concrete structure.

The illustration of Figure 2 includes, by way of example, the following four distinct varieties of wall panels 30 that have widths that may be defined by a whole number integer of the selected unit measure of width: panels 30A that are one unit measure of width wall panels, panels 30B that are four unit measures of width wall panels, panel 30C (that, as is discussed further below is typically utilized in formwork assemblies that include corners, but is included in the formwork assembly of Figure 2 for illustrative purposes) is a one unit measure of width directionality reversing wall panel, and panels 30D that are partially shown wall panels of at least three unit measures of width. Of course, the wall segments 27 and 29 illustrated in Figure 2 could have just as easily been assembled from different combinations of wall panels 30 having different unit measures of width. It will also be

noted (as illustrated in Figure 2) that the formation and use of wall panels 30 that have overall effective widths that are whole number integers of a selected unit measure of width permit the construction of walls in which the joints between the wall panels 30 of one wall segment and the joints between those of the opposing wall segment are not necessarily aligned, while nevertheless maintaining suitable alignment as between support panel connectors 38 on opposing inward-facing wall surfaces 31A, provided that a panel connector 38 is present at each unit measure of width across the width of each wall panel 30.

As noted, the wall panels 30 include suitable support panel connectors 38 disposed at a regular interval (which defines the unit measure of width) across their inward-facing surfaces 31A. The support panel connectors 38 are preferably elongate so as to extend substantially along the vertically-extending length of the wall panels 30, and are preferably configured for releasable interconnection with elongate support panels 36 or tensioning panels 40 as described further below.

The support panels 36 of the illustrated embodiment are (like the wall panels 30) elongate, and include terminal panel connectors 42 substantially along their longitudinal edges that are suitably configured for releasable interconnection with panel connectors 38. In the embodiment illustrated, the panel connectors 38 are female receptacles that mate with and receive male T-fasteners 42. The support panels 36 also include suitable perforations (not shown) to permit the cross-flow of concrete and the cross-placement of reinforcing steel rods. Basic selection of the size and positioning of the perforations would be within the ordinary skill of a person skilled in the art. The tensioning panels 40 may also be suitably perforated, and the basic selection of the preferred size and positioning of any such perforations would also be within the ordinary skill of a person skilled in the art.

The support panels 36A illustrated in Figure 2 are three unit measures of width wide, and include tensioning panel connectors 44 disposed on opposite sides of the support panel and constituting releasable tensioning panel engagement means for engaging and interconnecting a tensioning panel 40, each panel connector 44 being positioned one unit

measure of width from the nearest longitudinal edge of the support panel 36. The panel connectors 44 illustrated are female receptacles that mate with and receive male T-fasteners 46 located at the ends of an associated tensioning panel 40. As illustrated in Figures 5 through 8, support panels 36 of different widths (and either including interior panel connectors 44 or not) are also within the scope of the invention. Figure 7 is an illustration of support panel 36A; Figure 5 illustrates a one-unit-width support panel 36B; Figure 6 illustrates a two-unit-width support panel 36C that does not include any interior panel connectors 44; and Figure 8 illustrates a five-unit-width support panel 36D that includes interior panel connectors 44, each positioned one unit measure of width from the nearest longitudinal edge. Figures 18 through 22 illustrate these and additional variants of support panel 36 within partial assemblies of formwork. Other variants (such as, for example, six- or twelve-unit-width support panels, support panels that include interior panel connectors 44 along one side but not the other, and support panels that include interior panel connectors 44 positioned at two or three unit measures of width but none at one unit measure of width from either or both longitudinal edges) may, of course, also be utilized. Further, as discussed in the summary above, support panels 36 in which the connection between the support panel 36 and at least one tensioning panel 40 is permanent instead of releasable (such that the tensioning panel is integral with the support panel) are also within the scope of the invention.

The tensioning panels 40 of the embodiment illustrated in Figure 2 are also elongate and generally flat, and include terminal engagement means in the form of T-fasteners 46 at either end that are each suitably configured for releasable interconnection with a mating female receptacle of any of the panel connectors 38 of the wall panels 30 or with the interior panel connectors 44 of the support panels 36. Since the formwork of the illustrated preferred embodiments is manufactured from thin PVC plastic, the tensioning panels 40 must depend from the support panels 36 at a comparatively shallow angle (preferably not more than about 45°) in order to limit bending of the tensioning panels 40 when the wall panels 30 are pressed outwardly under the weight of concrete poured into the formwork assembly. By positioning interior panel connectors 44 one or more whole unit measures of width from the terminal edges of the support panels 36 (after making allowances for any

space taken up by the panel connectors themselves), a desired 45° angle of dependency of each of the tensioning panels 40 (or selected ones of same) from the nearest support panel 36 is easily arranged.

It will be appreciated that the panel connectors 38 of the wall panels 30 and the interior panel connectors 44 of the support panels 36 will preferably be of the same configuration in order to allow tensioning panels 40 having identical panel connectors 46 at either end to be set in either orientation; if the panel connectors 38 and the interior panel connectors 44 are not of the same configuration, then tensioning panels 40 that have differently configured panel connectors at either end would be required, thereby needlessly increasing the number of individual formwork components that may be required to complete a section of assembly. The configuration of both panel connectors 38 and panel connectors 44 as including a female receptacle, and the panel connectors of tensioning panels 40 being at each end a male T-fastener 46, achieves the foregoing objective and renders very simple the manufacture and ease of installation of the tensioning panels 40. It will also be appreciated that the terminal panel connectors 46 of the tensioning panels 40 will preferably be of the same configuration as the terminal panel connectors 42 of the support panels 36. This permits either a support panel 36 or a tensioning panel 40 to engage and interconnect with any given panel connector 38, thereby simplifying construction and facilitating scalability of a formwork assembly in accordance with the invention.

In the preferred embodiments shown in the drawings wherein the interval between consecutive panel connectors 38 (*i.e.* the selected unit measure of width) is calculated from the edge of the wall panels 30, and the joint between any two adjacent wall panels 30 is thus supported internally by a support panel 36 or a tensioning panel 40, all of the panel connectors 38 will need to be disposed slightly inwardly from the inward-facing surfaces 31A of the wall panels 30 in order to provide sufficient clearance for the placement of any panel connectors 38 that are associated in back-to-back relationship with a terminal panel receptacle 32 while maintaining the desired overall proportionality and

dimensional integrity of the assembly. Those panel connectors 38 that are not associated in back-to-back relationship with a terminal panel receptacle 32 accordingly include a neck 38A or similar spacer to provide the allowance that must be made for the panel connectors 38 that are so associated. It is, however, also within the scope of the invention to provide wall panels 30 in which the interval between panel connectors 38 (*i.e.* the selected unit measure of width) is calculated from a position that is offset from the longitudinal edges of the wall panels 30. In such embodiments, it would generally not be necessary to make as large an allowance when calculating the desired width of the support panels 36 because none of the panel connectors 38 would then need to be disposed inwardly to provide clearance for an underlying panel receptacle 32.

It is also noted that different kinds of known interconnection means (other than the conventional T-fasteners illustrated in the drawings), especially such kinds as do not take up much space, could be used to join together the formwork components. Although the interconnections between the components are preferably releasable in order to allow for the disassembly and reconfiguration of a formwork assembly before the concrete is poured, permanent interconnections may also be used.

Figures 3 and 4 provide detailed illustrations respectively of wall panel variants 30A and 30B that are have already been shown incorporated within the partial formwork assembly of Figure 2, and Figure 9 illustrates the directionality reversing wall panel 30C also shown in Figure 2. As will be seen with reference to the figures that follow, numerous other dimensional and ornamental variants of the wall panels 30 are contemplated within the scope of the preferred embodiments of the invention. By way of example, Figures 18 through 22 illustrate a two unit measure of width wall panel 30E, as well as other variants discussed further below.

Since the female receptacles 32 and male T-fasteners 34 utilized in the preferred embodiment illustrated in the drawings are complementary conventional fastening elements, such that each typical wall panel 30 (that is not a directionality reversing wall panel 30C) includes a male T-fastener formed along one longitudinal edge and a

corresponding generally channel-shaped female receptacle along the opposite edge, directionality reversing wall panels 30C (that include male T-fastener formed along both longitudinal edges or generally channel-shaped female fastener along both longitudinal edges) may also be provided, particularly if it is desired to construct walls or structures that include more than one corner. As will be set out in greater detail below, the preferred embodiment of inner corner element 48 (best seen in Figure 11) includes a pair of perpendicularly oriented inward facing channel-shaped female receptacles 47 that permit the perpendicular engagement of two wall panels 30 *via* their T-fasteners 34. The resulting requirement for a section of wall panels 30 that is bound by two inside corners to terminate with male T-fasteners 34 mandates the use of a directionality reversing wall panel 30C when more than one corner is sought to be negotiated.

Figures 5 through 8 illustrate several variants of support panel 36 in accordance with preferred embodiments of the invention, and assorted possible inter-relationships between the variants and other formwork components are illustrated in Figures 18 through 22. As already discussed, support panels 36 are preferably constructed in widths that are whole number multiples of the selected unit measure of width, and may or may not include interior panel connectors 44 that are preferably offset from the longitudinal edge of a support panel 36 by a whole number multiple of the unit measure of width.

Figure 10 is a detailed illustration of a tensioning panel 40 that shows the generally 45° and 135° relationship between inner surface 41 of tensioning panel 40 and its terminal T-fastener 46 at either end. Since tensioning panel 40 preferably extends between a wall panel 30 and a support panel 36 at a 45° angle, the angled relationship between the portions of tensioning panel 40 allow T-fastener 46 to engage cooperatively with both the interior panel connectors 44 of a support panel 36 and the panel connectors 38 of a wall panel 30.

As previously noted, the preferred embodiment of inner corner element 48 is best illustrated in Figure 11. Inner corner element 48 comprises a dual pair of perpendicularly oriented inward facing female receptacles 47 that correspond generally to the terminal

female panel receptacles 32 of wall panels 30, and outward facing female receptacles 49 that correspond generally to panel connectors 38. As seen in Figures 18 through 22, inner corner element 48 may thus releasably interconnect two perpendicularly presented wall panels 30 *via* their T-fasteners 34 without corrupting the proportionality of the framework assembly. The perpendicularly oriented outward facing pair of receptacles 49 of inner corner element 48 provide suitable connection points for support panels 36 or tensioning panels 40, as shown in the drawings.

Figure 12 provides a detailed illustration of four-way connector 50 in accordance with a preferred embodiment of the invention, and Figures 20 through 22 illustrate several possible inter-relationships of four-way connector 50 with other formwork components. As explained in the summary section above, four-way connector 50 allows support panels 36 (and/or tensioning panels 40) to be inter-connected within a formwork assembly in accordance with the invention so as to enhance the scalability of the formwork or to fortify its structural rigidity. The preferred embodiment of four-way connector 50 includes four receptacles 52 (that correspond in configuration generally to panel connectors 38) disposed about a box-shaped central portion 54. Like inner corner element 48, four-way connector 50 is suitably dimensioned (relative to the size of the engagement means selected) to permit the engagement of support panels 36 and/or tensioning panels 40 without corrupting the proportionality and dimensional integrity of the framework assembly.

Figure 13 illustrates a preferred embodiment of outer corner panel 56 that may be used to inter-connect the terminal outer wall panels 30 of two generally perpendicular wall sections in a formwork assembly. In the preferred embodiment, the outer corner panel 56 extends one unit measure of width perpendicularly from vertex 58 and terminates along one arm in a terminal female panel receptacle 57 (that corresponds generally to the terminal female panel receptacle 32 of a wall panel 30) associated in back-to-back relationship with panel connector 59 (that corresponds generally to the panel connector 38 of a wall panel 30), and along the other arm in a wall panel engagement 61 (that corresponds generally to the terminal male panel fastener 34). Other configurations, such as an outer corner panel having both arms terminating in either a T-fastener 61 or in the

combination of receptacle 57 and connector 59 are also contemplated within the scope of the invention, but are not required to be included in a formwork system that comprises the components thus far described.

Figures 14 trough 17 illustrate, by way of example only, various possible ornamental configurations of wall panels 30. Other ornamental configurations are, of course, possible, so long as any ornamentally configured wall panels 30 include suitable wall interconnection means 32 and 34 and support panel interconnection means 38 in the manner described above in relation to wall panels 30 in general. Wall panel 30F of Figure 14 is a four-unit-width wall panel that includes three puckers 60 that are set across its outer surface 31B at the selected unit measure of width in order to provide a generally consistent outer surface appearance in order to make the joints between adjacent wall panels 30 less noticeable. Wall panels 30G of Figure 15, 30H of Figure 15, 30I of Figure 16, and 30H of Figure 17 are all three-unit-width wall panels that include a central ornamental feature. Wall panel 30G includes columnar feature 62 and adjacent puckers 60, wall panel 30H includes rectangular feature 64, and wall panel 30I includes rounded feature 66.

As noted previously, Figures 18 through 22 provide representative illustrations of partial assemblies of formwork in accordance with preferred embodiments of the invention that demonstrate various possible inter-relationships of the formwork components to create walls and structures of various dimensions. As will be apparent from the discussion above, various alterations (such as changes in materials, lengths, widths, or surface appearances) may be made to the formwork components without departing from the scope of the invention. Note in particular that the configuration of the mating male and female fastening elements can be varied to suit design or manufacturing preferences; the key point is that the male and female elements must interlock (or at least, must do so if the adjoining elements are in tension; if they are in compression, an interfitting connection could be designed that would suffice), and preferably they should slide relative to one another easily to facilitate installation, while avoiding undue play that would unduly interfere with dimensional specifications. Further, the component elements can be reverse-designed so that certain elements described above as having a male fastener in a certain position are

instead provided with a female receptacle at that position, provided that the fastener with which such fastener is intended to interconnect is also reverse-designed to be male instead of female.

The use of discrete engagement means such as clips for securing adjacent wall panels 30 together (wherein the clips do not span between inner and outer wall panel segments so as to create a cellular structure of the sort that is common to prior-known modular formwork systems) are also contemplated within the scope of the present invention. One such embodiment is illustrated in Figures 23 to 29. Referring to Figure 23, there is illustrated a partial assembly 70 of formwork in accordance with a clip-joining embodiment of the invention. Elongate and substantially flat wall panels 72 and 74 have a terminal male panel fastener 73 at both vertical side edges dimensioned to interconnect with double female fasteners 75 presented on clip 76, and a series of adjacent wall panels 72 or 74 may be releasably interconnected to one another in edge-to-edge relationship *via* clips 76 to create wall segments. Although either male or female connectors may be presented on wall panels 72 and 74, male fasteners of the sort illustrated (coupled to female fasteners 75 on clips 76) have been found to provide suitable structural rigidity. The clips 76 and wall panels 72 also include suitable support panel connectors 77 for engagement of support panels 78 at suitable intervals (as discussed above). Tensioning elements 80 having terminal connectors 81 dimensioned for releasable interconnection with wall panels 72,74 and support panels 76 are also illustrated, as are inner corner elements 82 and outer corner dual wall panels 84. As in the embodiments described above, the wall panels 72, 74 include panel connectors 77 spaced apart at one unit measure of width across their inward-facing surface, and clip 76 also presents a panel connector 77, thereby to permit the engagement of support panels 78 at regular intervals in accordance with previously-described aspects of the invention.

As yet a further alternative, it will be appreciated by those of skill in the art that hermaphroditic fasteners that provide mating interlocking engagement could be used in substitution for the mating male and female fastening elements shown in the illustrated embodiments. Accordingly, the scope of the invention is to be construed in accordance

with the substance defined by the following claims, and not limited to the specific embodiments described in this specification.